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A STUDY ON THE OIL SUPPLY SYSTEM OF A HORIZONTAL ROTARY COMPRESSOR WITH VANE UTILIZED FOR OIL FEEDING

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ABSTRACT

For a horizontal rotary compressor which utilizes reciprocating movement of the vane for oil supply into lubrication elements, an analytical study has been carried out on the oil pumping mechanism. Energy equation has been applied to the oil flow inside the oil conveying pipe with oil feeding hole in the middle. Oil distributions into individual lubrication elements such as various bearing elements have also been analyzed by applying electric circuit network theory to the oil flow network. Fairly good agreement between calculations and experiments for the oil pumping rate has been obtained in a wide range of compressor speed.

1. INTRODUCTION

While a horizontal rotary compressor has an advantage of space saving over vertical type one, it requires some special considerations to accomplish sufficient oil supply to the lubrication components. For a horizontal rotary compressor, oil in the oil sump cannot be directly drawn into the shaft as in a vertical type. Okoma and Onoda [1] discussed various means of oil supply for horizontal rotary compressors: pressure differential system, gas carry system, and vane pump system. Among these, vane pump system is most likely appropriate for stable operation even in heavy load conditions. In the vane pump system, the reciprocating movement of the vane produced by the shaft rotation is utilized to pump up the oil into the shaft. Takebayashi, et al [2] replaced conventional valves by fluidic diodes in constructing a vane pump system and demonstrated successful operation of oil pumping.

In recent years, one of the widely used vane pump systems is the one which comprises vane, vane chamber, connecting pipe, oil feeding hole drilled on the pipe wall, and oil cap covering the shaft inlet. The working principles underlying this type of vane pump system, however, have not been fully understood, yet. In this study, numerical simulation on this vane pump system has been carried out to predict oil flow rates into various lubrication components as well as oil pumping rate by vane pump so that optimum design for the vane pump system can be assured.

2. VANE PUMP SYSTEM

A schematic diagram of the vane pumping system is shown in Fig. 2. Oil chamber beneath the moving vane is connected to the oil cap by a pipe which has a hole in the lowest location. As the vane reciprocates up and down, the oil inside the chamber (1) is forced to be delivered out of or into the chamber. At the oil hole (2) in the middle of the oil pipe, some amount of oil is sucked from or discharged into the oil sump (4), depending on the pressure difference across the hole. For the pipe portion from the oil hole to the oil cap, the oil flow changes its direction and magnitude during one cycle of the shaft revolution, somehow, resulting in net oil flow into the oil cap.

To describe the oil feeding phenomena driven by the vane pumping- pipe carrying -hole sucking mechanism, energy equations for the oil flows in the piping system can be written by the equations (1)-(3).

For the flow from the vane chamber to the oil feeding hole over the pipe length of l_1 ,

$$P_1 + Z_1 = P_2 + Z_2 + \frac{\rho}{2} V_1^2 \pm K_1^\pm \frac{\rho}{2} V_1^2 \pm f_1 \frac{l_1}{d} \frac{\rho}{2} V_1^2 + \frac{\rho l_1}{A_p} q_1 \quad (1)$$

For the flow from the oil feeding hole to the oil cap over the pipe length of l_3 ,

$$P_2 + Z_2 + \frac{\rho}{2} V_3^2 = P_3 + Z_3 \pm K_3^\pm \frac{\rho}{2} V_3^2 \pm f_3 \frac{l_3}{d} \frac{\rho}{2} V_3^2 + \frac{\rho l_3}{A_p} q_3 \quad (2)$$

For the flow through the oil feeding hole with opening area of A_n ,

$$P_2 + Z_2 = P_4 + Z_4 \pm K_2^\pm \frac{\rho}{2} V_2^2 \pm \frac{\rho}{2} \left(\frac{q_2}{A_2} \right)^2 \quad (3)$$

The subscripts 1, 2, 3, and 4 denote the locations shown in Fig. 2. The sign \pm is positive for $q \geq 0$, and negative for $q < 0$. A_p is the pipe cross sectional area, and A_2 is regarded as A_n for $q \geq 0$ and A_p for $q < 0$. K is the flow resistance and f is the friction coefficient. From open literatures, the flow resistance coefficients at pipe entrances and exits with various connection configurations can be found. The flow resistances at the oil feeding hole, K_2^+ and K_2^- were measured in terms of Reynolds number, and shown in Fig. 3.

Flow continuity at the oil feeding hole is written by the equation (4).

$$q_1 = q_2 + q_3 \quad (4)$$

The oil flow rate from the vane chamber, q_1 , is related to the vane velocity as in the equation (5).

$$q_1 = -A_v \times \frac{dx}{dt} \quad (5)$$

Where A_v is the vane cross sectional area, and x is the vane displacement. The environment pressure, P_0 , the pressure inside the compressor shell is close to the discharge pressure, and the pressure at the oil cap, P_3 , is higher than P_0 by the pressure difference across the partition and, if any, the pressure rise by the rotor fan. Four unknowns of q_2 , q_3 , P_1 , and P_2 can be obtained by solving the equations (1), (2), (3), and (4), simultaneously.

Calculated pressure traces are presented in Fig. 4, where the crank angle $\theta = 0^\circ$ corresponds to the vane position at BDC. Discharge pressure is used as reference value in the y-axis of the figure. The pressure variation inside the oil feeding hole, P_2 , is about half of that inside the vane chamber, P_1 . The chamber pressure has a peak value when the inward vane speed is maximum.

Patterns of oil flow rates at the pipe entrance (q_1), at the oil feeding hole (q_2), and at the pipe exit (q_3) are shown in Fig. 5. Sinusoidal pattern of the oil flow oscillation at the pipe entrance is distorted as it proceeds to the exit. It is mainly due to the difference in the flow resistance at the oil feeding hole between suction and discharge processes as illustrated in Fig. 3. Distortion in the pattern of the oil flow oscillation at the pipe exit results in net pumping of the oil flow. The net oil pumping rate was used for q_{ref} in the figure.

3. EXPERIMENT FOR OIL PUMPING RATE

To measure the oil flow rate by vane pumping, an experimental apparatus was made as in Fig. 6. While the inlet

hole to the oil gallery inside the shaft was closed on one side of the oil cap, a guiding tube was connected to the other side of the oil cap so that the oil flow into the oil cap by the vane pumping could be delivered out of the compressor shell. The out-delivered oil flow is collected in the oil collector and is made to return to the compressor via a circulating piping system, in which an oil pump and a valve are placed to control the oil flow through the flow meter in the piping system to be the same as that delivered out of the compressor. When the oil level in the oil collector is made to be sustained at constant elevation by adjusting the valve, the same flow rate in the circulating piping system can be assured. Since the compressor model was operated in an open air cycle, heating pad was provided to make the oil temperature high as in real operations.

Fig. 7 shows the measured oil pumping rates at various compressor speeds together with corresponding calculated values. All data were normalized by the measured one at 60 Hz. Fairly good agreement between them has been obtained.

4. INNER LUBRICATION SYSTEM

The oil pumped into the oil cap proceeds into the inner lubrication system which consists of several radial oil feeding holes, bearing surfaces, and exit vent as shown in Fig. 9. The oil flow network can be simulated by an equivalent electric circuit network [3]. In the analogy, the oil flow is analogized by electric current, the flow resistance by electric resistance, and the pressure difference by voltage

Fig. 8 shows an electrically analogous circuit to the present oil flow network of Fig.9. Kirchoff's laws are applied to the joints and the loops to find currents at various passages. The numbers in Fig. 9 are the fractions of the total oil flow rate by the vane pump at the corresponding locations. The calculation was made at ASHRAE/T condition and at the compressor speed of 3600 rpm. The portion of the oil return through the pump bearing groove into the oil cap is 0.442, so the oil flow rate which enters into the oil gallery becomes 1.442. While the oil flows along the gallery, some portion of it is fed into inner sliding surfaces through the radial oil feeding holes: 0.045 for motor bearing, 0.442 for pump bearing, and 0.114 for suction, and compression chambers. The leftover flowing out through the vent is 0.84.

5. CONCLUSIONS

For a horizontal rotary compressor whose vane is used for oil pumping into the shaft, with the aid of oil conveying pipe equipped with an oil feeding hole immersed in the oil sump,

- (1) Computer simulation program has been developed based on the analysis on the oil pumping mechanism.
- (2) Predictions on the oil pumping rate by the simulation have been found to be well compared with measurement data in a wide range of compressor speed.
- (3) Oil distribution into various lubrication elements has also been calculated by using analogous electrical circuit network modeling.

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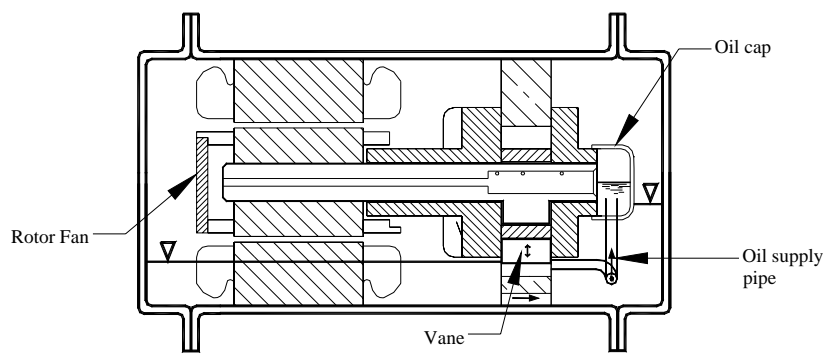


Fig. 1 Cross sectional view of horizontal rotary compressor

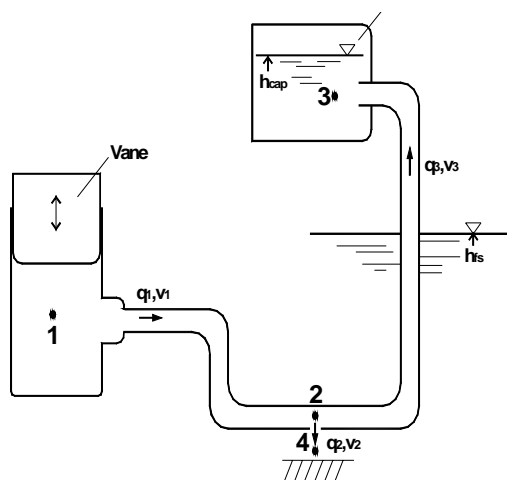


Fig. 2 Vane pumping system

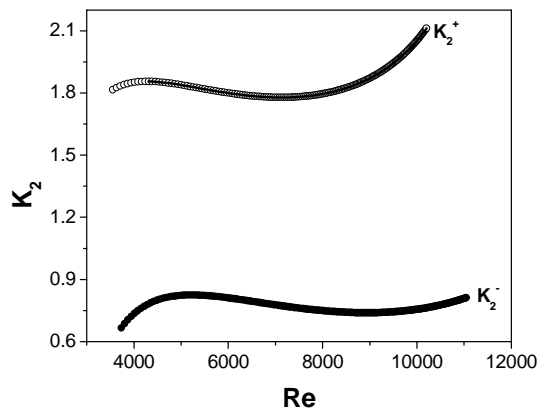


Fig. 3 Flow resistance at oil feeding hole

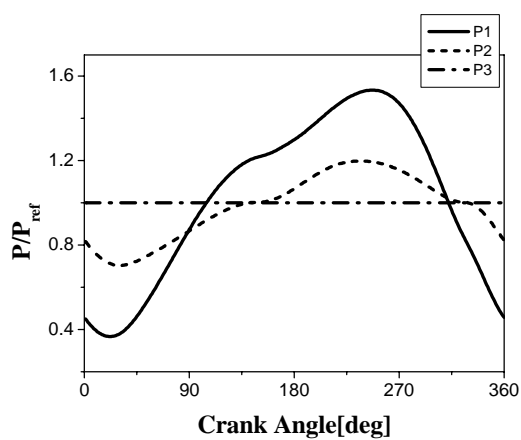


Fig. 4 Pressure traces in the vane pump

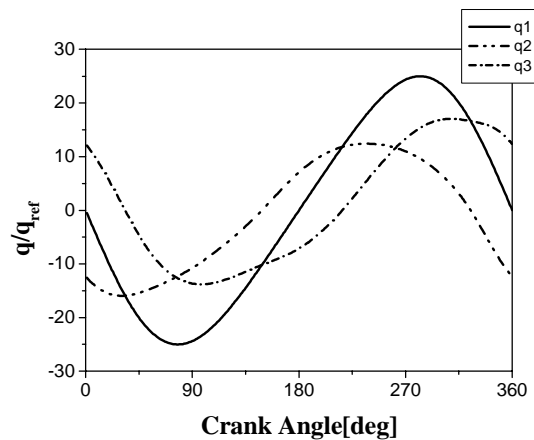


Fig. 5 Pulsating oil flows in the oil

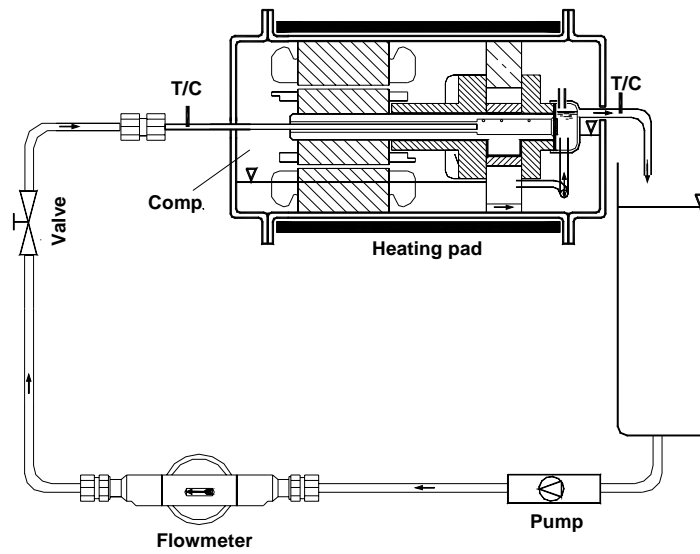


Fig. 6 Experimental apparatus for oil pumping rate

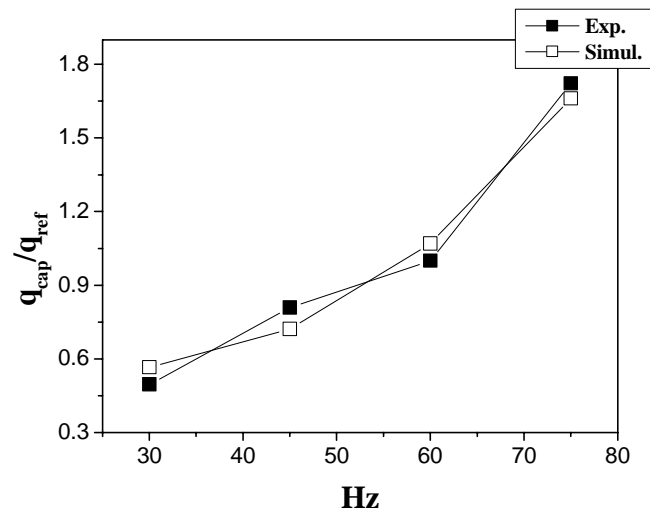


Fig. 7 Comparison of measurement and calculation for oil pumping rates

